Expert model of risk assessment for the selected components of smart city concept: From safe time to pandemics as COVID-19

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ABSTRACT

The purpose of the paper is to create an information, fuzzy risk assessment model to support the decision-making of Municipality management for the establishment and management of measures in the safe mode (regular) of City, emergency and disaster situations, in the selected components of Smart City concept. Research on this topic was motivated by the need for support, especially in emergency situations, such as the COVID-19 pandemic. It is proposed that the evaluation be carried out at local level within the framework of the Smart City concept and selected components integrated into the entity, including the Smart Security, Smart Healthcare, and Smart Environment components supported by the Smart WebGIS subsystem. The model also assesses proposed solutions for self-government financing to ensure the acceptable risk, and economic impact of decisions on the city budget within the Smart Budget aspects of selected components. Decision-making is based on intellectual analysis, processing of fuzzy data and use of fuzzy inference. The output of the model is the assessment of the risk of the municipality subsystems, taking into account the threshold for the functioning of the municipality subsystems, the linguistic interpretation of the level of risk and the acceptability of the tolerable risk resource. The model algorithm was used to create a web application to support the Municipal management for the above-mentioned agenda, from safe time to pandemics.

1. Introduction

A smart cities concept, which are being implemented by many countries, are created in order to create a motivating environment for the implementation of the innovative solutions for cities and municipalities and to find the suitable financing options that will ensure their implementation in real practice. According to the [1]; up to 80% of the population lived in cities by 2020 and according to the UN forecasts, up to two thirds of the population will live in cities by 2050. The growing importance of the smart cities concepts is influenced by its complexity as well as its significant society impact. The fact that more than three quarters of the companies are established in the cities in many countries and this share a characteristic of the employed population also contributes to this. The European countries differ in the structure of the urban centres, their industrial history in the creation and use of business chains and networks that also places the different demands on the planning processes in the transformation of the cities into the smart cities. The models of these transitions should be planned by the

countries' governments and supported by the different national strategies. This is due to their relations with the economic and social development programmes of the territories that are being developed within the countries. The development of the smart cities through the "smart" solutions has become a global trend in the recent years (for instance, Refs. [1–3].

The smart cities concept represents a comprehensive approach to the life of the urban regions that influences several social areas: infrastructure, culture, environment, energy, social service, and so forth. Each area represents a system of a few goals, that are interconnected and support sustainable development. The public administration subjects, the private sector subjects, and the civil society subjects enter these systems and thus, they create a heterogeneous platform for the life of the urban region. This heterogeneity is also a barrier to any standardisation of the processes that leads to the creation of international legally obligatory definitions or procedures. For this reason, the individual countries create their own smart concepts and methodologies that must be in a line with the global documents. The technologies such as

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"Internet of Things", "big data", "machine learning" and the others are getting to the forefront [4]. The smart cities are more efficient as they improve social inclusion and have more opportunities to ensure their growth, job creation, and so on. They can achieve this potential by an active creation and usage of the smart city strategies. The global strategies such as the Strategic Implementation Plan of the European Commission Programme are also important in this process [1,5].

The reason why it is necessary to create the efficient strategies for urban transformation is not only a heterogeneity of the smart cities dimensions altogether with the necessary complexity and a system approach, but also the nature of the capacities and tools that are necessary in the smart cities concepts. Their development is complex due to the diverse structure of the systems, which the decision-making processes take place within, as well as the risks arising from the challenging quantification of some of the assumptions, which the decision-making processes were based on. An example is the current pandemic that is of a global scale and it is difficult to quantify the economic and non-economic impacts, affecting all the spheres of economic and social life of the country. These consistent facts were a motivation for us to carry out our study focused on the selected aspects of the smart cities concept and their application possibilities for the needs of real practice from the safe time to the pandemic period. Our study is limited and focused on the following selected components of the Smart City concept: the Smart Security, the Smart Healthcare, and the Smart Environment, supported by the Smart WebGIS subsystem and the Smart Budget aspects of selected components.

The main goal of the paper is to create an information, fuzzy risk assessment model to support the decision-making of Municipality management for the establishment and management of measures in the safe mode (regular) of City, emergency and disaster situations, in the selected components of Smart City concept.

The study provides an answer to a basic research question: What tool can we create to support the right and coordinated decisions of municipality leadership and financial management, especially in emergencies such as the COVID-19 pandemic, which endanger human and human health and lives?

What is novel in the presented approach? Much work is devoted to the Smart City concepts, but few researchers use intellectual analysis, a systems approach, fuzzy mathematics and fuzzy logic to analyze experiences in various community security regimes, from peacetime to pandemics. In addition, no studies have yet been carried out on selected components integrated as an entity into the Smart City concept for emergency and disaster purposes: as Smart Security, Smart Healthcare, and Smart Environment subsystems, supported by Smart WebGIS and Smart Budget aspects of selected subsystems. The task of the authors was to create a model of information fuzzy risk assessment to support quality decision-making, for the creation and management of preventive measures in security, emergency, and disaster situations within the concept of Smart City and its selected components.

This paper is organized as follows. In Section 2, we describe the formal problem statement and the model of input data for assessment of the situation provided by a group of experts based on their knowledge, skills, and at least 15 years of practical experience. We present the fuzzy mathematical risk assessment model for decision making quality in different modes within the Smart City concept. In Section 3, we outline the results of simulation experiment. In Section 4, we discuss the results of the expert model and its software (SW) developed in the study. In Section 5, we conclude the paper and present the main results. We expand the ideas for future work and improvements.

1.1. Literature Review

Although the numerous studies have been published at the time of the pandemic declaring the impacts on the business and economy of the countries, the studies aimed at a development of a methodological platform in the decision-making processes influenced by the pandemic are absent [6–10]. We have seen the emergence of the numerous research studies whose research trajectories have been linked to policymaking, but which have been largely compensatory (e.g. Refs. [11–16]. This means that their procedural focus has been related to the declaration of the recommendations on how to overcome the fatal effects of the crisis for small and medium enterprises (SMEs) in the various sectors through the relevant policies in order to prevent the corporate bankruptcies and the financial failures caused by the outstanding commitments to the financial institutions (e.g. Refs. [7,17,18]. Another group of the research studies critically evaluate the usefulness of the risk management in the companies operating within the risk management systems [19,20]. It has been shown that the current crisis scenarios set in the different types of the companies, as well as sizes, cannot flexibly reflect the changed conditions on a global scale that manifest the pandemic caused by COVID-19 [8,21–23]. For this reason, it is necessary to change the concepts of the risk scenarios creation, which would be a part of the quality decision-making mechanisms implemented within the set strategies of regional development (or development of cities and territorial units) [24,25]. The success of the creation of these decision-making mechanisms depends primarily on a quality database, a systemic approach to solution of the multidimensional development programmes, efficient knowledge of the risk management, and human resources in the decision-making processes.

The relevance of this study is proven by the significant worldwide research, scientific publications and pandemics COVID-19. Today, the Smart City concept is dedicated to many publications and conferences, developing start-ups and innovative projects to improve and stimulate city development [26,27]. In addition, there are already publications on the impact of COVID-19 on the specificities of the municipality's activities in the Smart City concept [28]; Tan Lii Inn, 2020). In the period of obtaining and processing of intellectual knowledge in the concept of Smart City, the task is to formalize the opinions of experts regarding the object of study. There are no universal ways of transforming experienced human expert knowledge into a knowledge base of fuzzy inference systems. In addition, our study uses expert information that reflects the substantive features of the studied subsystems of the municipality and is given in natural language. In this case, the description is fuzzy, and it is advisable to use fuzzy set theory to reflect knowledge of the object of study and to reduce the risk. To properly assess risk, it is necessary to learn how to scientifically model information uncertainty by drawing formally described boundaries between reliable knowledge, knowledge with a certain level of certainty and what we do not know [29]. The issue of data mining is mainly considered in terms of statistics considered in the paper [30]. In the works [31] prove scientifically the advantages of studying complex objects of functioning in different modes, using system analysis [32]. identified 12 application areas related to smart cities from a textual analysis of 1234 news articles; these are "smart device," "smart environment," "smart home," "smart energy," "smart building," "smart transportation," "smart logistics," "smart farming," "smart security," "smart health," "smart hospitality," and "smart education.". Despite the emergence of such cases, the understanding of data use for smart cities remains limited in the literature as described in the paper [32]. The foregoing justifies and confirms the relevance of our study to the development of an informative fuzzy risk assessment model using intellectual analysis, systematic approach, fuzzy data processing and fuzzy inference. The different components of a smart city include smart infrastructure, smart transportation, smart energy, smart healthcare, and smart technology. These components are what makes the cities smart and efficient. Information and communication technology (ICT) are enabling keys for transforming traditional cities to smart cities. The two closely related emerging technology frameworks Internet of Things (IoT) and Big Data (BD) make smart cities efficient and responsive [33].

2. Materials and methods

2.1. Formal problem statement

The formulation of the estimation problem is formulated as follows. Let us have the subsystems of the municipality $C_1, C_2, ..., C_n$ within the Smart City concept. They should assess the risk to the quality of decision-making, the establishment and management of preventive measures, depending on the regime (safe, emergency, disaster) and to propose the necessary funding to ensure acceptable risk.

The Smart City Emergency Mode is a freelance mode where the quality of a municipality's system or that of an external environment falls outside the regular mode intervals in such a way that the trend is observed until the next disaster mode.

The Smart City Disaster Mode is a freelance mode in which a municipality's system goes from a workable state to such a disabling, catastrophic state that it is fundamentally impossible to transition to a workable state.

Let us have a set of indicators (criteria) according to which we will evaluate the subsystems of a municipality $K = (K_{1j}, K_{2j}, ..., K_{m_j j}), j = \overline{1, n}.$

We offer a hybrid evaluation based on the expertise of the municipality's subsystem managers and data mining within the Smart City Data Sources.

Each indicator of a municipality subsystem is evaluated by a linguistic variable by a regional expert or manager in an industry or municipality subsystem. We will present such a term-set of linguistic variables as the level of situation in a subsystem of a municipality to create preventive measures described by the criterion K. Term-sets offer the following $T = \{L; BA; A; AA; H\}$, where: L - "low level"; BA - "level below average"; A - "average level"; AA - "above average level"; H - "high level".

On the other hand, we get a quantitative estimate for each metric, within Smart City Data Sources. Depending on the type of data, their structure, frequency of receipt, subjectivity of receipt and other characteristics, the membership function is investigated and constructed separately for each criterion. This will allow comparisons of the obtained estimates, by translating them into a normalized scale, to reveal the inaccuracy and uncertainty of the data obtained, which will improve the quality of decision making made using the intellectual analysis of such data. Models, methods and tools of intellectual knowledge analysis, based on fuzzy sets and membership functions, for various fields of application are described in detail in (Voloshyn et al., 2018). As a result, we will get a quantitative assessment q of the situation for each criterion, from the interval [0; 1], to make decisions, to create and manage preventative measures. Input data, risk assessment for the quality of decision making, regarding the creation and management of preventive measures, are presented in Table 1 Separately for municipality subsystems.

Where T_{ij} – variable of term-set T for the i-th indicator, the j-th municipality subsystem C_j; q_{ij} – quantitative assessment from the interval [0; 1], i-th indicator on the j-th subsystem, $j = \overline{1, n}, i = \overline{1, m_j}$. Number of evaluation criteria m_j varies with the subsystems of the municipality C_j.

Thus, we can formally present a fuzzy model, risk assessment for the quality of decision-making on the creation and management of preventive measures against the situation regimes, in the following form:

$$A(C; T; q; M; S) \rightarrow R(\mu(R); L; F). \tag{1}$$

The input data model are: C – municipality subsystems; T – expert level of situations for creating preventive measures, which is evaluated on the basis of multiple criteria of the municipality subsystems; q - quantitative assessment of the situation obtained with the components within Smart City Data Sources; M – taking into account the views of the head management municipality (DMs) on the scenario of the deployment of events; S – situation mode (safe, emergency, disaster).

At the output of the evaluation model we have: $\mu(R)$ – risk assessment for the quality of decision-making by the municipality, the creation and management of preventive measures (separately, both for the subsystems of the municipality and for the whole city); L – linguistic interpretation of the level of risk for the quality of decision making, regarding the creation and management of preventive measures; F – the estimated amount of resources required relative to the risk received.

The solution to this problem can be clearly demonstrated in the form of a structural diagram of a fuzzy model of risk assessment in the safe mode, emergency and catastrophe, Fig. 1. Fig. 2 presents a structural diagram of decision making and components in different modes.

2.2. Evaluation criteria for municipal management subsystems of integrated component

We propose a set of risk assessment criteria for the creation and management of preventive measures in the proposed subsystems of a municipality: C_1 – Smart Security; C_2 – Smart Healthcare; C_3 – Smart Environment.

We offer the criteria for evaluating the Smart Security Municipality subsystem include the following indicators that provide for the collection, analysis and exchange of information for the effective prevention of offenses, situation control, effective response to emergencies, minimizing the risk of injury, damage to life and property (RAND Corporation, 2015):

SS_1 – single dispatch system situation: records management, computer-based dispatching system;

SS_2 – the situation regarding the operation of GIS systems;

SS_3 – the situation on emergency support systems, communications and information sharing between public security agencies;

SS_4 – security systems analytics situation (video analytics, social media and media analysis, statistical analysis, trend analysis and forecasting, identification of potentially dangerous situations);

SS_5 – the situation regarding face recognition technologies;

SS_6 – situation with radar collecting systems and mobile solutions (GPS subscriber position determination);

SS_7 – the situation of various sensors (sensors as part of the Internet of Things) and related embedded solutions, including the use of sensors to improve the health and safety of officers;

SS_8 – the situation regarding the training of police officers by web technologies in their special programs;

SS_9 – the situation on network infrastructure to support web technologies (new IpV6 protocols, 5G Internet generation), including ships and correctional facilities;

SS_{10} – the situation of common national/regional electronic file systems for criminals and offenders, including common directories and classification systems.

The criteria for evaluating the Smart Healthcare Municipality subsystem are as follows:

SH_1 – the situation regarding the health and well-being of city dwellers;

SH_2 – The situation regarding the availability of records to the doctor, and time costs of care including availability of electronic document;

SH_3 – the situation regarding the state of constant monitoring, the possibility of remote consultation and response to health hazards;

Table 1
Input data.

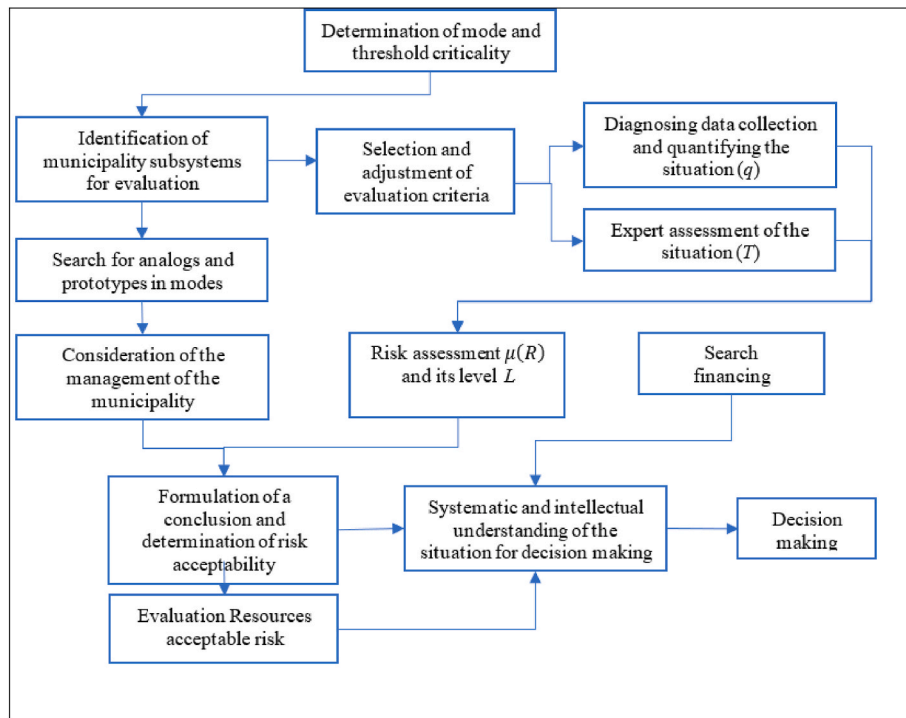| Criterions evaluation	C_1		C_2		...	C_n	
1	T_{11}	q_{11}	T_{12}	q_{12}	...	T_{1n}	q_{1n}
2	T_{21}	q_{21}	T_{22}	q_{22}	...	T_{2n}	q_{2n}
3	T_{31}	q_{31}	T_{32}	q_{32}	...	T_{3n}	q_{3n}
...	...	...	...	...	...	...	...
m_j	$T_{m_j 1}$	$q_{m_j 1}$	$T_{m_j 2}$	$q_{m_j 2}$	...	$T_{m_j n}$	$q_{m_j n}$

Fig. 1. Structural diagram of a fuzzy risk assessment model for a municipality.
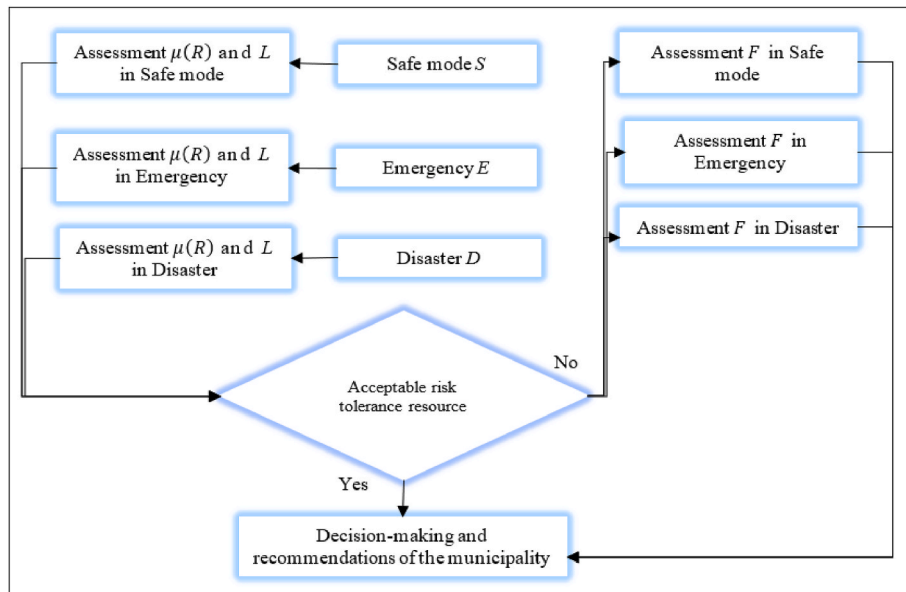

Fig. 2. Structural diagram of decision making and components in different modes.

SH_4 – the situation regarding the state of health protection, by ensuring the safety of the environment, labor, food, etc.;

SH_5 – the situation of health promotion, including the impact on the social determinants and reduce health inequality indicators;

SH_6 – the situation with the prevention of disease, including early detection of health problems;

SH_7 – the situation regarding the provision of health care by qualified medical personnel sufficient capacity and training and improve their skills;

SH_8 – the situation in the field of health care provision by qualified auxiliary staff of sufficient capacity and training and training;

SH_9 – the situation regarding the repair of medical institutions, the purchase of modern equipment, medicines and financing;

SH_{10} – the situation with information and education activities, communication and social mobilization in the interests of the health of residents.

The criteria for evaluating the Smart Environment subsystem are as follows (Worldwide Air Quality Monitoring Data Coverage, 2017; Lavigne et al., 2017):

SE_1 – the situation regarding air quality control systems;

SE_2 – the situation regarding integrated solid waste management systems;

SE_3 – situation regarding the use of data from water meters, sensors and other intelligent devices to forecast demand and availability of re-

sources, optimize feed volumes, identify losses, implement savings programs, optimize water infrastructure and resources;

SE_4 – the situation of "smart systems" for wastewater treatment;

SE_5 – the situation regarding the systems of prediction and autonomous adaptation of the grids to improve the reliability, connection of new energy sources;

SE_6 – the situation regarding system optimization and energy savings, analysts forecasting and preventive maintenance of equipment;

SE_7 – the situation of smart city lighting systems and support systems for technical staff.

The set of criteria is open and the municipality may always add other indicators.

2.3. Fuzzy mathematical risk assessment model for decision making quality in different modes: from safe time to pandemics

We describe the mathematical model according to the following algorithm [34].

Step 1. Fuzzification of the hybrid input data municipality subsystems.

In the first step, we will perform the fuzzification operation of the input hybrid data. To do this, each input value $(T_{ij}; q_{ij})$ we set the value of the membership function $\mu(T_{ij})$. It is then necessary to build membership rules to obtain a normalized estimate of the input.

Let the term-set linguistic variables $T = \{L; BA; A; AA; H\}$ we will represent on some numerical interval for delimitation of terms $[a_1; a_6]$, where $L \in [a_1; a_2]$, $BA \in [a_2; a_3]$, $A \in [a_3; a_4]$, $AA \in [a_4; a_5]$, $H \in [a_5; a_6]$. The value of the partition intervals can be set and changed, in the process of using the actual data of the municipality's subsystems.

We calculate the criterion estimates O_{ij}, using linguistic variables T, quantitative estimates q and the value of intervals $[a_1; a_6]$, using the following characteristic function:

$$O_{ij} = \begin{cases} a_2 \cdot q_{ij} & if \quad T_{ij} \in L; \\ a_3 \cdot q_{ij}, & if \quad T_{ij} \in BA; \\ a_4 \cdot q_{ij}, & if \quad T_{ij} \in A; \\ a_5 \cdot q_{ij}, & if \quad T_{ij} \in AA; \\ a_6 \cdot q_{ij}, & if \quad T_{ij} \in H. \end{cases} \quad (2)$$

This will bring together quantitative assessments and expert opinions. As a result, we get an objective assessment of the situation on site for the evaluated subsystems of the municipality, which will increase the degree of creation and management of preventive measures.

To compare the data it is necessary to normalize the obtained estimates. Without reducing the generality, let us introduce the rule of identity using the S-like membership function, or other similar type. For example, if we take the interval value $[a_1; a_6] = [0; 12]$, then the membership function (3) will have the form:

$$\mu(O_{ij}) = \begin{cases} 0, & O_{ij} \leq 0; \\ \dfrac{(O_{ij})^2}{72}, & 1 < O_{ij} \leq 6; \\ 1 - \dfrac{(12 - O_{ij})^2}{72}, & 6 < O_{ij} < 12; \\ 1, & O_{ij} \geq 12. \end{cases} \quad (3)$$

The membership function constructed in this way indicates that the value obtained $\mu(O_{ij})$ will go to 1, if the high level of the municipality subsystem and the quantitative assessment of the situation will go to 1.

So, in the first step, we reveal the subjectivity of expert opinions and move from fuzzy expert linguistic and quantitative assessments to normalized and compared.

Step 2. Aggregating the evaluation of a municipality's subsystems for preventive events deployment with respect to considerations of the DMs.

Let the DMs set weights for each criterion of the municipality's subsystems v_{ij}, $i = \overline{1, m_j}$, $j = \overline{1, n}$, at some interval $[1; 10]$. Otherwise,

the criteria may be equally important. Determine the normalized weights, respectively [35]:

$$w_{ij} = \frac{v_{ij}}{\sum_{i=1}^{m_j} v_{ij}}, j = \overline{1, n}. \quad (4)$$

Next, we construct the membership function as one of the proposed convolutions, depending on the psychosomatic mood of the DMs, regarding the unfolding of events:

$$M_1(C_j) = \frac{1}{\sum_{i=1}^{m_j} \frac{w_{ij}}{\mu(O_{ij})}} - \text{pessimistic scenario for unfolding events;} \quad (5)$$

$$M_2(C_j) = \prod_{i=1}^{m_j} (\mu(O_{ij}))^{w_{ij}} - \text{cautious scenario for unfolding events;} \quad (6)$$

$$M_3(C_j) = \sum_{i=1}^{m_j} w_{ij}\mu(O_{ij}) - \text{average scenario for unfolding events;} \quad (7)$$

$$M_4(C_j) = \sqrt{\sum_{i=1}^{m_j} w_{ij}(\mu(O_{ij}))^2} - \text{optimistic scenario for unfolding events.}$$
$$(8)$$

where w_{ij} ($i = \overline{1, m_j}$, $j = \overline{1, n}$,) normative weights for each criterion.

There is the following subordination between them: $M_1(C_j) \leq M_2(C_j) \leq M_3(C_j) \leq M_4(C_j)$.

Step 3. "Risk Trend" for the scenario of the deployment of events.

We design evaluation $M_g(C_j)$, $g = \overline{1, 4}$ on the "Risk Trend". To do this, it is necessary to construct a membership function that forms the following dependency: the greater the aggregate assessment of the municipality's subsystems, the lower the risk. Considering this, we consider the dependence in the form of a linear Z-like membership function [36]:

$$M_g(C_j) = \begin{cases} 1, & R_g(C_j) < a; \\ \dfrac{b - R_g(C_j)}{b - a}, & a \leq R_g(C_j) \leq b; \\ 0, & R_g(C_j) > b. \end{cases} \quad (9)$$

where a, b numerical values. Because we evaluate risk, then it is natural to consider risk as a percentage scale: $a = 0$, $b = 100$. For example, when it comes to 100% risk, the maximum critical risk is associated. Because the value of the membership function $M_g(C_j)$, $g = \overline{1, 4}$ known and known numerical values, then we express $R_g(C_j)$ from formula (10):

$$R_g(C_j) = 100(1 - M_g(C_j)), \ g = \overline{1, 4}; \ j = \overline{1, n}. \quad (10)$$

The values obtained $R_g(C_j)$ – this is an assessment of the "Risk Trend" projection for an aggregate assessment of the municipality's subsystems for preventive measures of event deployment, in the light of the management's considerations.

Step 4. Risk assessment in safe mode, emergency and disaster.

Let us have three modes $SM = \{S; E; D\}$ risk assessment for the quality of decision-making, the creation and management of preventive measures: $S = \{\text{safe mode}\}$; $E = \{\text{emergency mode}\}$; $D = \{\text{disaster mode}\}$.

With the increase of emergency, rapidly changing values that affect the stability of any system. This clearly increases the risk of decision making. To do this, we introduce the concept of some a priori set allowable values - "threshold of the possibility of functioning of the subsystems of the municipality".

In order to adequately interpret the dependence of risk on the quality of decision-making regarding the creation and management of preventive measures against modes, we construct the following function:

$$\mu\left(R_g\left(C_j\right)\right) = \begin{cases} 0, & R_g\left(C_j\right) < 0; \\ \left(\dfrac{R_g\left(C_j\right)}{100}\right)^k, & 0 \le R_g\left(C_j\right) \le 100; \\ 1, & R_g\left(C_j\right) > 100. \end{cases} \qquad (11)$$

$g = \overline{1,4}$; $j = \overline{1,n}$. Where κ – "threshold of the possibility of functioning of the subsystems of the municipality". The value of this threshold varies depending on the modes in which the DMs needs to make a decision. Experimentally put: $k = \frac{5}{3}$ for the safe mode; $k = \frac{4}{3}$ for the emergency mode; $k = \frac{2}{3}$ for the disaster mode.

The value obtained $\mu_{SM}\left(R_g\left(C_j\right)\right)$ – it is a risk assessment for the quality of decision-making by the municipality management, for the creation and management of preventive measures for the g-th reasoning of the DMs regarding the scenario of the deployment of events, j-th subsystem of the functioning of the municipality and in view of the mode SM.

Step 5. Aggregation of risk assessment of a municipality system by modes.

If the municipality's management intends to make decisions separately for the municipality's subsystems, then this step is skipped. Otherwise, we define one aggregate risk assessment of the municipality's functioning.

Let the DMs set weights for each subsystem β_j, $j = \overline{1,n}$, at some interval [1; 10]. Otherwise, the criteria may be equally important. Then, similarly, we define the normalized weights:

$$\alpha_j = \frac{\beta_j}{\sum_{j=1}^n \beta_j}, j = \overline{1,n}. \qquad (12)$$

Next, we build, for example, a medium-weight convolution, separately for the three risk assessment modes $SM = \{S; C; E\}$:

$$\mu_{SM}\left(R_g(C)\right) = \sum_{j=1}^n \alpha_j \cdot \mu_{SM}\left(R_g\left(C_j\right)\right); SM = \{S; E; D\}, \ g = \overline{1,4} \qquad (13)$$

Step 6. Defuzzification of the data and determining the level of risk.

According to the values of risk assessment $\mu_{SM}(R_g(C))$ or $\mu_{SM}(R_g(C_j))$ $g = \overline{1,4}$; $j = \overline{1,n}$, $SM = \{S; C; E\}$ present linguistic interpretation of the level of risk, of the set $L = \{VLR; LR; AR; HR; VHR\}$, for quality decision making, for the establishment and management of preventative measures in the safe, emergency and disaster modes [34]:

✓ $\mu_{SM}(R_g(C))$ or $\mu_{SM}(R_g(C_j)) \in [0; 0,2)$ – VLR: very low the level of risk;
✓ $\mu_{SM}(R_g(C))$ or $\mu_{SM}(R_g(C_j)) \in [0,2; 0,4)$ – LR: low the level of risk;
✓ $\mu_{SM}(R_g(C))$ or $\mu_{SM}(R_g(C_j)) \in [0,4; 0,6)$ – AR: average the level of risk;
✓ $\mu_{SM}(R_g(C))$ or $\mu_{SM}(R_g(C_j)) \in [0,6; 0,8)$ – HR: high the level of risk;
✓ $\mu_{SM}(R_g(C))$ or $\mu_{SM}(R_g(C_j)) \in [0,8; 1]$ – VHR: very high the level of risk.

A graphical interpretation of the fuzzy risk assessment model, taking into account the situation deployment mode and the derivation of linguistic assessment, is presented at Fig. 3.

The level of risk can be considered as the amount of losses from the undesirable consequences of the influence of any factors and decision-making, regarding the creation and management of preventive measures in the process of functioning of the municipality.

Step 7. Conclusion and determination of risk acceptability.

Acceptable resource risk of the Smart City – the duration of the period of operation of a municipality's systems in some mode during which the assessment and level of risk due to the possible influence of risk factors do not exceed the a priori set threshold for the possibility of functioning of the municipality's subsystems.

Since the risk may, in the general case, be acceptable or unacceptable, then the output will formulate a logical statement depending on
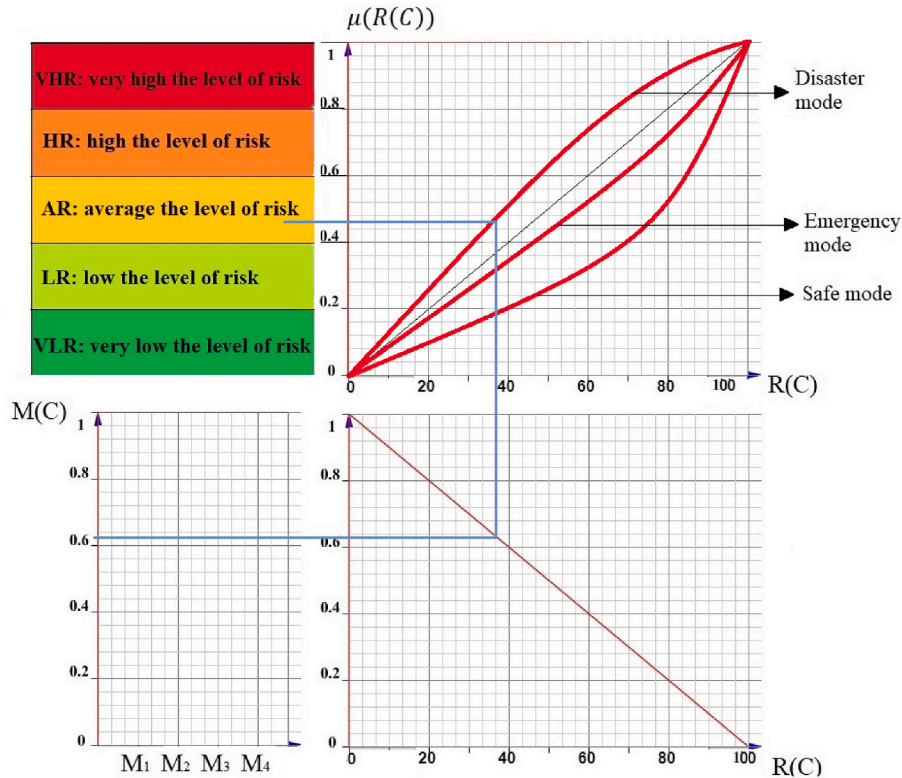
Fig. 3. Graphical interpretation of fuzzy model ($M(C)$ – aggregate evaluation of municipality subsystems; M_1, M_2, M_3, M_4 – event deployment scenarios; $R(C)$ – assessment of the projection of "Risk Trend" on the aggregate assessment of the municipality's subsystems; $\mu(R(C))$ – risk assessment).

the resource level of the tolerable risk $Y = \{acceptable; unacceptable\}$.

As a result of the calculations we get a linguistic interpretation of 5 levels of risk $L = \{VLR; LR; AR; HR; VHR\}$, obtained with 4 event deployment scenarios based on DMs considerations $M = \{M_1; M_2; M_3; M_4\}$ and 3 situation modes $SM = \{S; E; D\}$. So we have $5*4*3 = 60$ different options for the level of tolerable risk resource representing the knowledge matrix.

Then the object with three inputs and one output is analyzed:

$$Y = Z(L, M, SM) \tag{14}$$

where Y - output linguistic variable, L, M, SM - input linguistic variables. Z - operator that matches the output variable Y, at input variables L, M, SM (rule of logical conclusion).

The Knowledge Matrix of an acceptable resource is a dimension matrix 60×4, where each row is a specific combination of the values of the input variables, for which the DMs specifies one of the possible values of the output variable. The Knowledge Matrix defines a system of logical expressions - "If, Then, Else" that relate the values of input variables L, M, F with one of the possible values of the tolerable risk resource $Y = \{acceptable; unacceptable\}$.

Next, an expert, or group of experts, for each level of risk tolerance Y builds rules for the input of linguistic assessments:

If in the system/subsystem of the municipality {Smart Security; Smart Healthcare; Smart Environment}

in the safe mode (S) risk assessment and DMs considerations (M_4) risk level interpretation low (LR) or very low (VLR), and for other DMs considerations (M_1, M_2, M_3) linguistic interpretation of the level of risk is not below average. (AR)

Or in the emergency mode (E) risk assessment and DMs considerations (M_3, M_4) risk level interpretation low (LR) or very low (VLR), and for other DMs considerations (M_1, M_2) linguistic interpretation of the level of risk is not below average. (AR)

Or in the disaster mode (D) risk assessment and DMs considerations (M_2, M_3, M_4) risk level interpretation low (LR) or very low (VLR), and for other DMs considerations (M_1) linguistic interpretation of the level of risk is not below average. (AR)

Then tolerable risk resource $Y = \{\textbf{acceptable}\}$

Else tolerable risk resource $Y = \{\textbf{unacceptable}\}$.

If the DMs of a municipality accepts a resource of acceptable risk, that is, the assessment and the level of risk do not exceed the acceptable values, then the algorithm is completed with the obtained evaluation and conclusion. Otherwise, we take risk mitigation measures and provide the necessary resources to do so, step 8.

Step 8. Estimate the required amount of resources according to the amount available and the risk received.

Additional resources are required to ensure risk tolerance. For the management of the municipality, the main resource is the city budget. They are limited and support from the state budget is needed to overcome an emergency or catastrophic situation. Of course, in case of an emergency, other resources, such as labor, technical, industrial, natural, scientific and other, are needed to overcome it. Without reducing the generality, in our study, we mean financial resources as resources.

We calculate the amount of funding needed for the municipality's subsystems to ensure acceptable risk:

$$F_j = FA_j \cdot \left(1 + \mu_{SM}\left(R_g\left(C_j\right)\right)\right), j = \overline{1,n} \tag{15}$$

Or in the case of comprehensive financing of the entire municipality system:

$$F = FA \cdot \left(1 + \mu_{SM}\left(R_g(C)\right)\right), SM = \{S; E; D\}, g = \overline{1,4}. \tag{16}$$

where FA / FA_j – available municipality resource, or accordingly j-th subsystems of its functioning. F / F_j– the estimated amount of resources required relative to the risk received.

3. Results

The results of the research were tested for an example of a developed risk assessment information model. The verification of the algorithm was trained on the example of the Municipal Management of the City of Košice, the Slovak republic. In addition, we will show the decisions on the necessary financing to ensure acceptable risk.

Based on the proposed criteria, the expert team assessed the expert level of the situations for the creation of preventive measures. Also, quantify the situation with the help of components within „the Smart City Data Sources of Košice" presented in an experimental way to demonstrate the algorithm. The input data are presented in Table 2.

Risk assessment is carried out according to the proposed algorithm.

Step 1. Fuzzification of the hybrid input data municipality subsystems.

In the first step, we will perform the fuzzification operation of the input hybrid data. For this purpose, the term-set of linguistic variables T we present on a numerical interval for delimitation of terms, for example: $L \in [0; 2]$, $BA \in [2; 4]$, $A \in [4; 7]$, $AA \in [7; 10]$, $H \in [10; 12]$. Calculate the criterion estimates using formula (2) and the values of the membership function of (3), Table 3.

Steps 2–3. Aggregating the evaluation of a municipality's subsystems for preventive measures of event deployment based on the considerations of the DMs and the Trend of Risk for the scenario of event deployment.

Let the DMs set the intervals for each criterion of the subsystems of the municipality [1; 10]. Determine the normalized weights by (4). Let the DMs decide that the events unfold in the average scenario (7). According to formula (10), we calculate the estimate of the projection of "Risk Trend" on the aggregate assessment of the subsystems of the municipality, regarding preventive measures of event deployment, the results are presented in Table 4.

Step 4. Risk assessment in safe mode, emergency and disaster.

Let us have three modes $SM = \{S; E; D\}$ risk assessment for the quality of decision-making, the creation and management of preventive measures. DMs installed "threshold of the possibility of functioning of the subsystems of the municipality": k = 5/3 for the safe mode; k = 4/3 for the emergency mode; k = 2/3 for the disaster mode. Then, using formula (11), we calculate the risk assessments for the quality of decision-making by the municipality, Table 5.

Step 5. Aggregation of risk assessment of a municipality system by modes.

We define one aggregate risk assessment for the municipality.

Let DMs set intervals for each subsystem from the interval [1; 10] for the municipal systems, respectively – (10; 9; 8). By (12), we define the normalized weights – $\{0, 37; 0, 33; 0, 3\}$. Next, by formula (13) we construct a weighted average convolution for different modes: $\mu_S(R_3(C)) = 0, 208$; $\mu_E(R_3(C)) = 0, 284$; $\mu_D(R_3(C)) = 0, 532$.

Step 6. Defuzzification of the data and determining the level of risk. The risk level is presented in Table 6.

Steps 7–8. Conclusion, determination of risk acceptability and assessment of required resources.

We conclude for a general evaluation of the subsystems of the municipality.

If in the system of the municipality in the safe mode (S) risk assessment and DMs considerations (M_3) risk level interpretation low (LR) **Then** tolerable risk resource $Y = \{\textbf{acceptable}\}$

If in the emergency mode (E) risk assessment and DMs considerations (M_3) risk level interpretation low (LR) **Then** tolerable risk resource $Y = \{\textbf{acceptable}\}$

If in the disaster mode (D) risk assessment and DMs considerations (M_3) risk level interpretation average (AR) **Then** tolerable risk resource y $Y = \{\textbf{unacceptable}\}$

As part of the study, was developed innovative software in the form of a web application, called "SMART CITY platform", based on the constructed algorithm, Fig. 4.

Table 2
Input data.

Criterion	Smart Security		Criterion	Smart Healthcare		Criterion	Smart Environment	
	T	q		T	q		T	q
SS_1	AA	0,55	SH_1	A	0,72	SE_1	AA	0,93
SS_2	A	0,75	SH_2	H	0,85	SE_2	A	0,93
SS_3	H	0,83	SH_3	AA	0,91	SE_3	H	0,97
SS_4	AA	0,69	SH_4	A	0,86	SE_4	AA	0,75
SS_5	A	0,78	SH_5	A	0,78	SE_5	H	0,82
SS_6	AA	0,82	SH_6	AA	0,77	SE_6	A	0,92
SS_7	BA	0,94	SH_7	H	0,94	SE_7	BA	0,37
SS_8	H	0,89	SH_8	A	0,96			
SS_9	A	0,55	SH_9	AA	0,29			
SS_{10}	AA	0,86	SH_{10}	BA	0,78			

*T – term-set, q – quantitative assessment.

Table 3
Fuzzification of the hybrid input data.

Criterion	Smart Security		Criterion	Smart Healthcare		Criterion	Smart Environment	
	O	$\mu(O)$		O	$\mu(O)$		O	$\mu(O)$
SS_1	5,5	0,4201	SH_1	5,04	0,3528	SE_1	9,3	0,8988
SS_2	5,25	0,3828	SH_2	10,2	0,9550	SE_2	6,51	0,5814
SS_3	9,96	0,9422	SH_3	9,1	0,8832	SE_3	11,64	0,9982
SS_4	6,9	0,6388	SH_4	6,02	0,5033	SE_4	7,5	0,7188
SS_5	5,46	0,4141	SH_5	5,46	0,4141	SE_5	9,84	0,9352
SS_6	8,2	0,7994	SH_6	7,7	0,7432	SE_6	6,44	0,5706
SS_7	3,76	0,1964	SH_7	11,28	0,9928	SE_7	1,48	0,0304
SS_8	10,68	0,9758	SH_8	6,72	0,6128			
SS_9	3,85	0,2059	SH_9	2,9	0,1168			
SS_{10}	8,6	0,8394	SH_{10}	3,12	0,1352			

*O – criterion estimates, $\mu\ (O)$ – membership function value.

Table 4
Weights of criteria and evaluating the scenario of the deployment of events.

Criterion	Smart Security		Criterion	Smart Healthcare		Criterion	Smart Environment	
	v	*w*		*v*	*w*		*v*	*w*
SS_1	10	0,119	SH_1	10	0,118	SE_1	10	0,185
SS_2	9	0,107	SH_2	9	0,106	SE_2	8	0,148
SS_3	9	0,107	SH_3	9	0,106	SE_3	7	0,130
SS_4	10	0,119	SH_4	8	0,094	SE_4	7	0,130
SS_5	9	0,107	SH_5	7	0,082	SE_5	6	0,111
SS_6	7	0,083	SH_6	8	0,094	SE_6	9	0,167
SS_7	8	0,095	SH_7	10	0,118	SE_7	7	0,130
SS_8	7	0,083	SH_8	9	0,106			
SS_9	7	0,083	SH_9	9	0,106			
SS_{10}	8	0,095	SH_{10}	6	0,071			
M_3	0,576		M_3	0,591		M_3	0,678	
$R(C_3)$	42,39		$R(C_3)$	40,88		$R(C_3)$	32,19	

*v – weights of criterions; w – normalized weights of criterions; M – convolution of the views of the head management municipality, regarding the unfolding of events; R (C) – assessment of the "Risk Trend" projection for an aggregate assessment of the municipality's subsystems.

From the open data on the budget of the city of Košice, we simulated the expenditures for 2020 according to the examined subsystems Smart Security, Smart Healthcare, Smart Environment for safe mode, emergency mode, and disaster mode. As can be seen from Fig. 4 the greater the difference between the available budget and the necessity to ensure the manageability of processes in the appropriate mode of operation, the managers should pay priority attention to the subsystem of the

municipality. The obtained initial estimates for the heads of the municipality show in terms of which subsystems of the municipality need funding. In this case, it is necessary to analyze the activities of services, review the budget, identify mechanisms to improve the situation in the appropriate mode of operation. If it is the safe mode, it is necessary to react immediately, if we predict the situation for future modes, the emergency, or the disaster, we should take proactive decisions. The

Table 5
Risk assessments for quality decision making.

Mode	Smart Security	Smart Healthcare	Smart Environment
S	0,239	0225	0,151
E	0,318	0303	0,221
D	0,564	0551	0,470

*S – safe mode; E − emergency mode; D – disaster mode.

Table 6
Risk level.

Mode	Smart Security	Smart Healthcare	Smart Environment	Aggregation of risk assessment of a municipality system
S	LR	LR	VLR	LR
E	LR	LR	LR	LR
D	AR	AR	AR	AR

presented estimate of the impact on the current budget of the municipality and the justification of additional expenditures on preventive measures in crisis situations should enable city managers to prioritize processes and resources for the implementation of the necessary measures. Managers should prioritize crisis mitigation processes and the following key actions: promote the protection of the health and lives of city citizens, promote the targeted distribution of vital goods and services necessary for the survival of the population, support the protection of vital resources whose disruption or malfunction due to risk factor may endanger or disrupt the economic operation of the city or endanger the life and health of the population. The local government provides these processes with its own human, material, technical and financial resources, complementary and in cooperation with state resources, to support the resolution of crisis situations in the regions. Prioritizing the resources of self-government for the implementation of necessary measures requires not to rely on state aid, but flexibly reallocate human resources and funds originally planned in the city budget for investments, modernization, grants, cultural and sporting events, immediately to implement and finance the above processes and measures. The algorithm for supporting the decision-making processes of local government managers were tested on the example of the city of Košice and currently represents a limitation of the presented model for local government at the level of up to 300,000 inhabitants. However, the model has the potential to share existing innovative knowledge and further

expand its modules and functionalities, which is also the intention of further scientific work of the authors in cooperation with the local government.

Based on calculations and in situations of the COVID-19 pandemic, it follows that in percentage terms it is necessary to increase the budget of the city of Košice for selected subsystems, for example, by 53.2% to ensure an acceptable risk due to the response to COVID-19 for the catastrophic regime.

In Fig. 4 we can see the percentage of the requested increase in the municipality budget in the relevant mode. This percentage is determined from the total cost of financing the municipal budget. In addition, the total value of the funding is the estimated number of resources needed due to the jointly acquired risk for the three subsystems, Smart Security, Smart Healthcare and Smart Environment of the municipality. Due to the fact that the budget was revised five times in 2020, also due to the fight against the COVID-19 pandemic, we received an acceptable source of tolerable risk in emergency mode [37].

4. Discussion

Most risk situations are not, in principle, a complete group of random events. Therefore, multiple events from this set are likely to occur simultaneously. The occurrence of one or more events from a plurality of risk situations does not preclude the occurrence of other events of that plurality. Therefore, the projected amount of funding we need is a fuzzy concept. The amount may change rapidly depending on the change in the stages of the freelance mode. On the other hand, it gives the opportunity to justify additional financing of the municipality or its subsystems in the safe mode, for the creation and management of preventive measures.

The paper builds a fuzzy risk assessment model for decision-making quality, the creation and management of preventive measures in safety, emergency, and disaster within the Smart City concept and the proposed municipal subsystems Smart Security, Smart Healthcare, Smart Environment, supported by the Smart WebGIS subsystem and the Smart Budget aspects of selected component. The model is able to assess the level of risk and to draw a fuzzy conclusion about the acceptability of risk. Decision-making is based on intellectual analysis, systematic approach, processing of fuzzy data and the use of fuzzy logical inference. The model reveals the inaccuracy of the input assessments, enhances the validity of further management decisions regarding the creation and management of preventive measures. The output of the model is the assessment of the risk of the municipal subsystems, taking into account
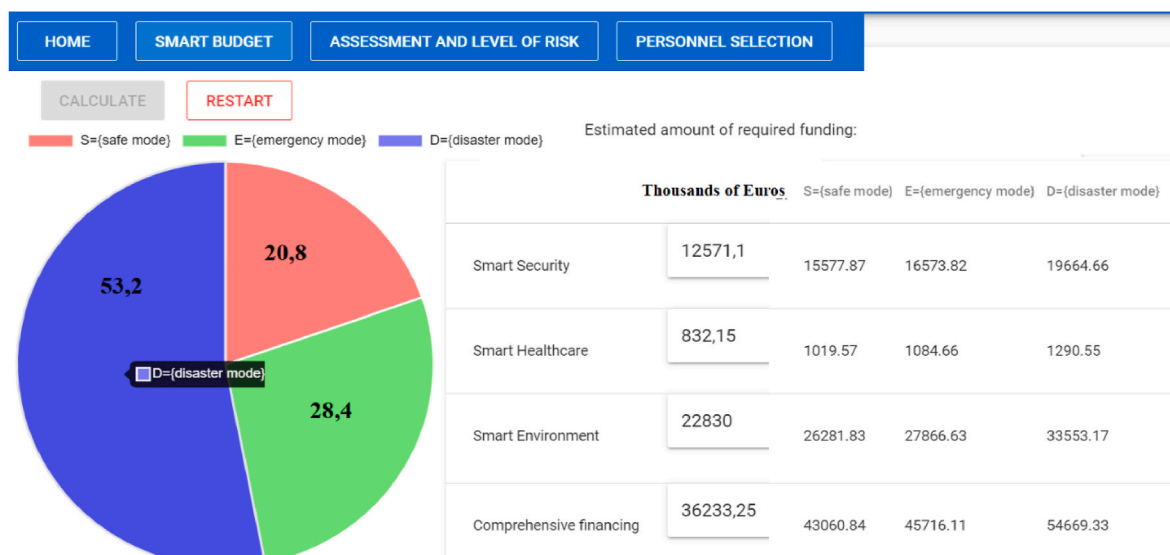
Fig. 4. SMART CITY web platform.

the threshold for the possibility of the functioning of the subsystems of the municipality, the linguistic interpretation of the level of risk, and the acceptability of the tolerable risk resource and the estimated amount of funding needed.

The model developed in the study has several advantages, namely: it increases the objectivity of the expert assessments using the input hybrid data: the linguistic variables of the situation in the municipality subsystem and the quantitative assessment within Smart City Data Sources; draws up an aggregate assessment of the municipality's subsystems for preventive action deployments based on the DMs considerations; builds risk assessment in the safe mode, emergency and disaster, using the threshold for the possibility of functioning of the municipality's subsystems; determines the level of risk with linguistic interpretation; reveals uncertainties of fuzzy expert judgment and concludes by determining the level of risk acceptability using an acceptable resource knowledge matrix; builds an estimate of the required amount of resources, based on the amount available and the risk received.

The disadvantages of this model include the use of different types of membership functions, which can lead to ambiguity of the final results.

The development of the smart cities concepts in Slovakia lags significantly behind the other economically developed countries, while from a point of view of policymaking, the basic document for the development of the smart cities concept at the national level of state administration is still absent. The development of the urban regions is regulated by the Concept of Urban Development of the Slovak Republic until 2030 prepared by the Ministry of Transport and Construction of the Slovak Republic [38,39]. In addition to this document, the development of the cities in the Slovak Republic is and will be managed in accordance with the global documents and the principles such as the 2030 Agenda for Sustainable Development, New Urban Agenda on housing and sustainable urban development HABITAT III and the Amsterdam Pact [40]. The development of the cities also takes into account national conceptual and strategic documents in the field of regional and territorial development, environment, transport, energy, social issues, and so forth. The smart cities concepts are absent in these documents. They create a part of the research and innovation strategies for a smart specialisation in the Slovak Republic (RIS3SK) that represents the basic framework strategic document for the support of research and innovation and sustainable economic growth. To create an efficient smart city concept at the local level, it is necessary to build up a strategic vision of the city, which the relevant stakeholders identify with and that is supported by the long-term regulations, and the strategic concept of the smart city development.

5. Conclusion

The development of the smart cities is also closely linked to the sharing of knowledge at the local, national and international levels. For the creation of the efficient smart cities concepts with the active decision-making mechanisms, it is important to subsequently share knowledge between the cities, the companies, the non-profit sector subjects, and so forth. From a point of view of the country, it is necessary to create the conditions for building a smart city in the area of one of the existing cities of the different sizes, to discover the opportunities to share knowledge about the smart solutions in the cities and their effects, to prepare a comparative platform in several dimensions within the smart cities concepts, and so forth. Successively, it is possible to develop new methods for benchmarking the smart cities and to specify metrics that would design the basement for a uniform methodology for all the cities in the country. In addition to these evaluation activities, the European Union smart city indicators, metrics and standards, as well as key performance indicators, are being developed within the European Union in order to better compare and to evaluate the effects of the smart cities and to suitably quantify the strategic goals and the indicators in the countries' development activities. The development and creation of the decision-making models for the smart cities will also enable a better

definition of the requirements for the smart cities standards for stakeholders on the city platform as well as the definition of the standards for a comparison between the cities. The development of the quality decision-making models will also support the more efficient creation of new business models within the innovative local partnerships, support for cooperation within the entire ecosystem as well as within the individual processes such as financing, procurement, and so forth. We also see their importance in a support of the creation of strategic investment and the development packages that are used as the strategic concepts by several countries and whose basic platform is innovation and the smart cities as well as regional development. A systemic approach is required to link these concepts (smart cities versus strategic investment and the development packages) that support the development of the new decision-making processes and the risk management that would cope with the laboriously predictable changes in the economies of the countries and the world as we are witnessing in the ongoing pandemic caused by COVID-19.

The actual task of developing an informative fuzzy risk assessment model to support decision making, to create and manage preventive measures in different modes of operation, within the Smart City concept and the innovative proposed municipal subsystems Smart Security, Smart Healthcare, Smart Environment, supported by the Smart WebGIS subsystem and the Smart Budget aspects of selected components. The first such results were obtained:

- Substantiates, within the Smart City concept, the relationship between the Smart City Data Sources and the risks they carry, describes the uncertainty and subjectivity of decision-making based on such data;
- Formulate basic concepts and definitions that characterize the features of the Smart City system in different modes of operation, namely: risk situation in the Smart City management; Smart City Emergency Mode; Smart City Disaster Mode; threshold of the possibility of functioning of the subsystems of the municipality; Acceptable resource risk of Smart City; Knowledge Matrix of an acceptable resource;
- Presents the inputs of the evaluation of the municipal management subsystems in a hybrid way, based on the expertise of the DMs of the municipality subsystem and the intellectual analysis of data obtained within the Smart City Data Sources. Structural diagrams of a fuzzy model for risk assessment model for a municipality and decision making and components in the different modes are demonstrated;
- Many risk assessment criteria have been developed to create and manage the preventive measures in the municipality's subsystems, namely: 10 measures for Smart Security, 10 measures for Smart Healthcare and 7 measures for Smart Environment. The criteria are proposed in light of the official documents, standards, concepts of Smart City's international development;
- A fuzzy mathematical risk assessment model was proposed to support decision making according to an 8-step algorithm based on expert hybrid data, using linguistic and quantitative variables. Aggregate estimates of municipality subsystems for preventive deployment events based on DMs considerations (pessimistic/cautious/average/optimistic scenario for unfolding events). One aggregate risk assessment of the municipality in different operating modes is displayed. Linguistic interpretation is derived - the level of risk considered as the amount of losses from the undesirable consequences of the influence of any factors and decision making, regarding the creation and management of preventive measures in the functioning of the municipality. All this allows to reveal the uncertainties of expert opinions and data obtained, substantiate the degree of decision making and draw adequate conclusions, taking into account the mode of functioning of the municipality;
- Within the framework of the mathematical model, a logical statement of the rule of belonging to the input linguistic assessments and a

matrix of knowledge of the acceptable resource, depending on the level of the risk tolerable resource, are formulated;

- The developed risk assessment model to support decision-making has been tested on the example of the Municipal Management of the City of Košice. Developed innovative software in the form of a web application, called "SMART CITY platform", based on the constructed algorithm. As a result, due to the situation of the COVID-19 pandemic in the pessimistic scenario (for the disaster mode) it is necessary to finance the city budget by 53.2% in the relevant components Smart security, Smart health, a Smart Environment.

The rationality of the accepted risk assessments and the level of sources of tolerable risk for the quality of decision-making in the management of municipalities in different operating regimes proves the advantages of the developed model, which can be adapted to a specific city. The validity of the obtained results is ensured by the correct use of intellectual analysis, systematic approach, fuzzy data processing and fuzzy deduction, which is also confirmed by the research results. Further research into this problem can be seen in extending the functionality of the web application to evaluate other components within the Smart City concept, such as Smart Mobility and Transport, etc.

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CRediT authorship contribution statement

Beata Gavurova: Conceptualization, Literature review, Formal analysis, Writing – original draft, Writing – review & editing, Manuscript Reviewing, Funding acquisition, References. **Miroslav Kelemen:** Conceptualization, Methodology, Formal analysis, Writing – original draft, Manuscript Reviewing, Funding acquisition. **Volodymyr Polishchuk:** Methodology, Literature Review, Formal analysis, Writing – original draft, Manuscript Reviewing, References.

Appendix A. Supplementary data

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